UCRL-PRES-225682

OVERVIEW OF EDGE SIMULATION LABORATORY

R. H. Cohen, M. Dorr, J. Hittinger, T. Rognlien, M. Umansky, A. Xiong, X. Xu, LLNL;

E. Belli, J. Candy, P. Snyder, G.A.,

P. Colella, D. Martin, T. Sternberg, B. Van Straalen, LBNL;

K. Bodi, S. Krasheninnikov, UCSD

APS-DPP Meeting, Philadelphia

November 2, 2006

Work at UC LLNL performed under the auspices of the U.S. Department of Energy under contract No. W-7405-Eng-48

What is the ESL?

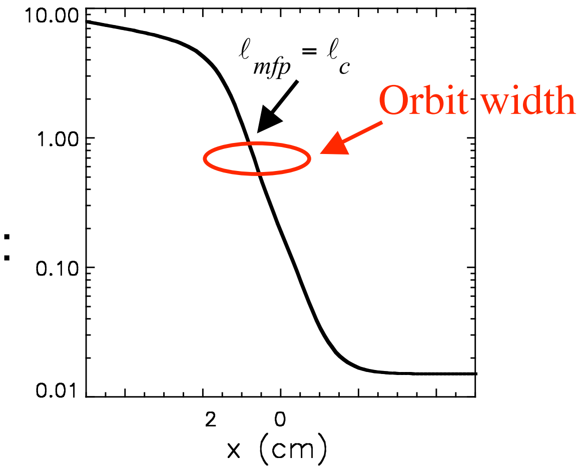
edge
simulation
laboratory

- ESL = Edge Simulation Laboratory
  - Project to develop an edge gyrokinetic code using continuum [evolving f(x,v) on a 5-D mesh] methods
  - New OFES/OASCR base-program activity
  - Collaboration: LLNL, GA, UCSD, LBNL, CompX, Lodestar, PPPL. Others welcome.
  - Outgrowth of LLNL LDRD project which has developed TEMPEST
  - Will develop code based on experience from TEMPEST, GYRO, and other continuum GK codes

We are building a continuum edge gyrokinetic code

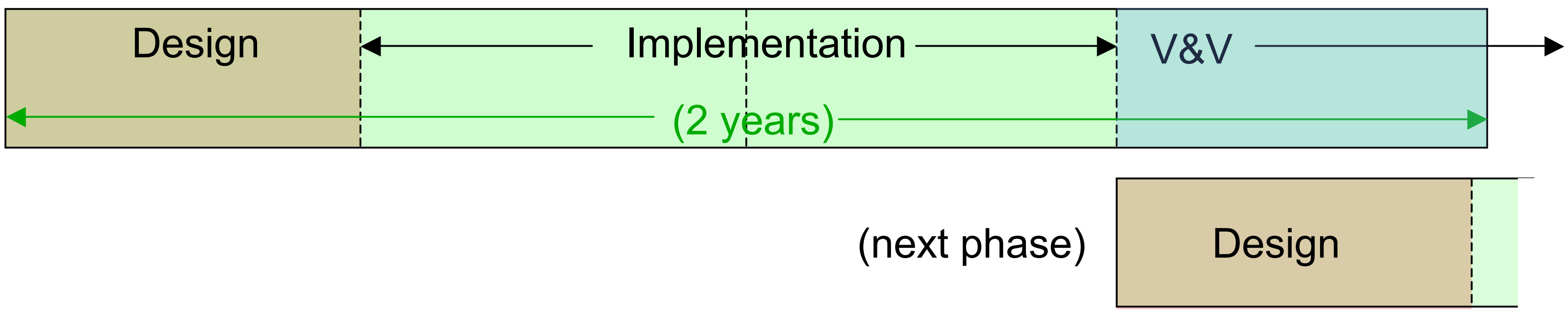
- We need a edge kinetic code because:
  - Ion drift orbit width Δ ~ pedestal width L_p
  - Mean free path ~ connection length
- We settled on a continuum approach, because:
  - Concerns about noise in PIC simulations due to:
    - Inapplicability of δf
    - Still need accuracy in places/times with small fluctuations
  - Expense of fully nonlinear GK PIC collision operators
  - Applicability of advanced fluid numerical techniques, e.g.
    - High-order discretizations
    - AMR in x + v
    - Implicit timestepping
  - Successful examples (core codes): GYRO, GS2, GENE…
- Such an important/challenging problem merits both approaches

DIII-D mean free path/connection length

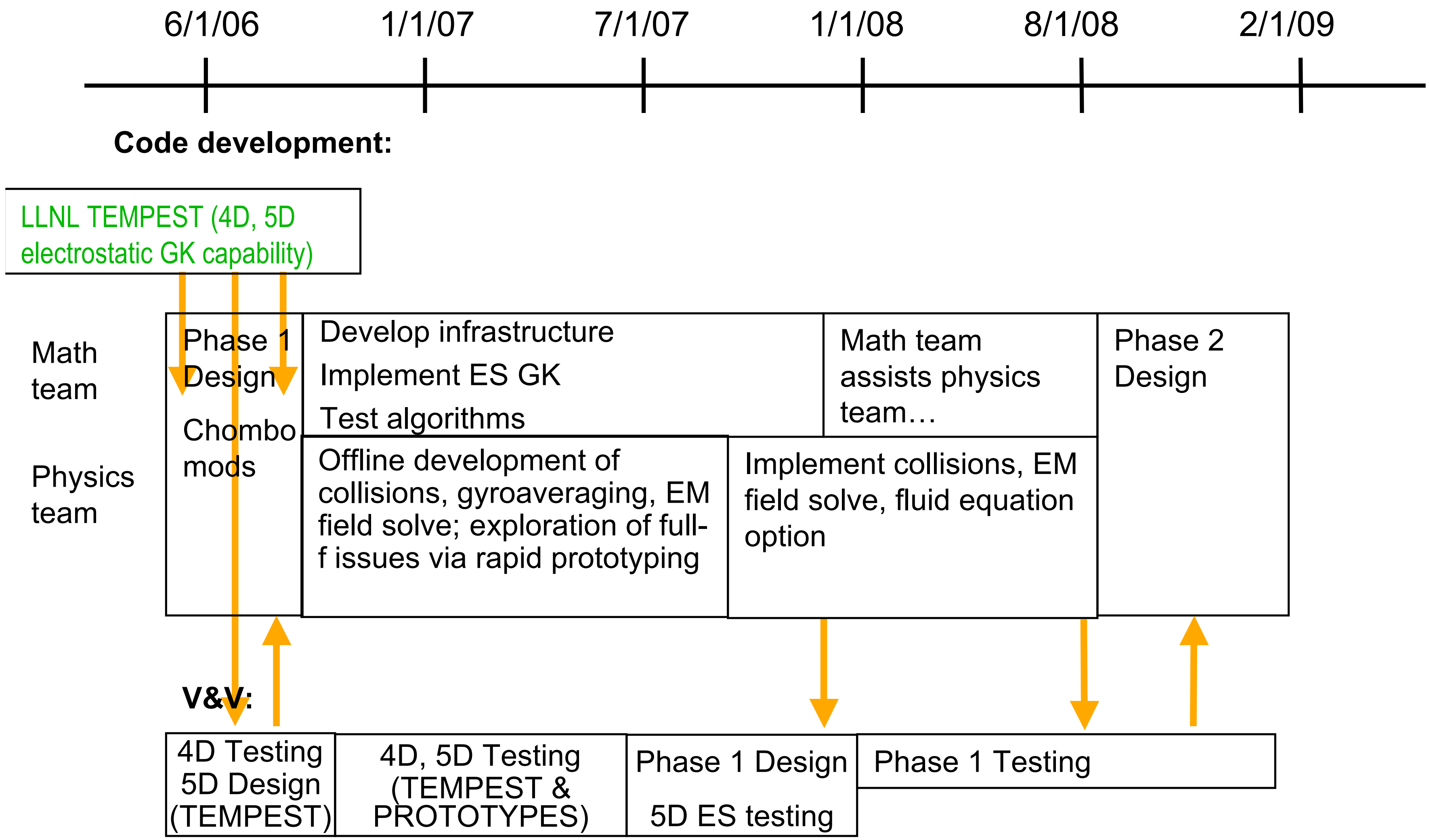


The ESL project is structured around the notion of "spiral software design"

- ~ 18 mo - 2 year cycles:



ESL Plan as of 10/1/06



Near-term (1-year) ESL activities

edge
simulation
laboratory

- LLNL/LBNL math/CS team
  - Port TEMPEST to LBL's Chombo infrastructure (nearly done)
  - Design and implement basic structure for Phase 1 code.

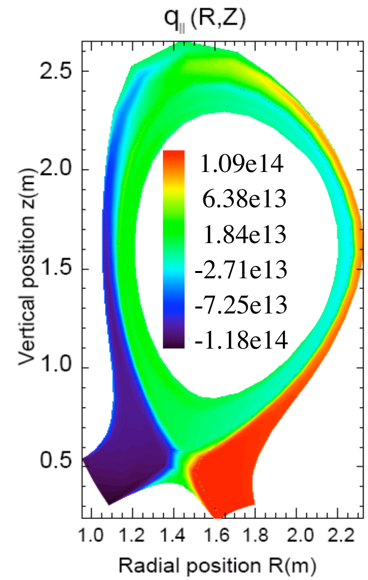
  MEANWHILE:
- Physics team:
  - LLNL-FEP
    - TEMPEST: Complete 5-D electrostatic; V&V; further algorithm exploration; physics studies (base program)
    - Provide software for gyro-averaging and collisions
  - GA: EGK rapid-prototype code, to
    - explore algorithmic issues associated with $v_{||}$-μ and strong kinetic nonlinearity
    - Develop electromagnetic solver
  - UCSD: diffusion operator & related B.C. issues (with LLNL)
- LLNL/LBNL math/CS team
  - Explore algorithmic issues associated with $v_{||}$-μ
  - Develop high-order finite-volume discretizations on mapped grids
- Everyone: contribute design documents for Phase 1 code

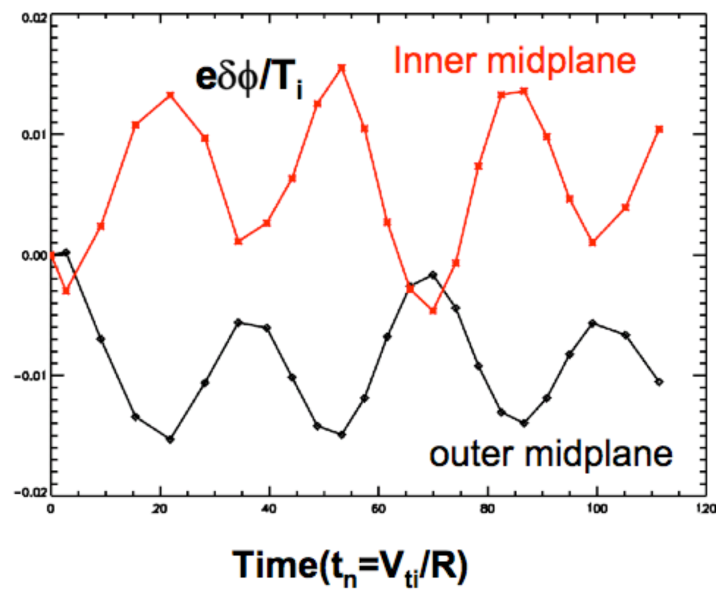
TEMPEST is in effect ESL's "Phase 0" code

- ε,μ coordinates for velocity space ($\varepsilon = mv^2/2 + q\Phi_0$)
  - Advantage: accurate representation of parallel advection
  - Challenges: cut cells at $v_{||} = 0$; $\pm v_{||}$ sheets
- Electrostatic
- Full-f (and linearized option)
- 4D (2x, 2v), 5D(3x, 2v) versions from same source
- Full divertor or circular (ring) geometry
- Multiple collision options
  - Krook
  - Finite-volume operator, with coefficients from either
    - Analytic Rosenbluth potentials (linearized collisions)
    - CQL Fokker-Planck package
- High-order (4th, 5th) spatial differencing
- Kinetic or adiabatic electrons
- Python interface facilitates problem setup, mid-run and post-run data analysis

TEMPEST is operational in 4D and has produced initial 5D runs

- 3D (1x, 2v) runs
  – “Pastukhov” collisional endloss tests
- 4D runs
  – Neoclassical benchmarks and divertor-geometry studies
  – GAM tests
  – Anomalous transport coefficients being implemented (“kinetic UEDGE”)
- First 5D low-resolution runs
  – Stable drift wave
  – ITG mode

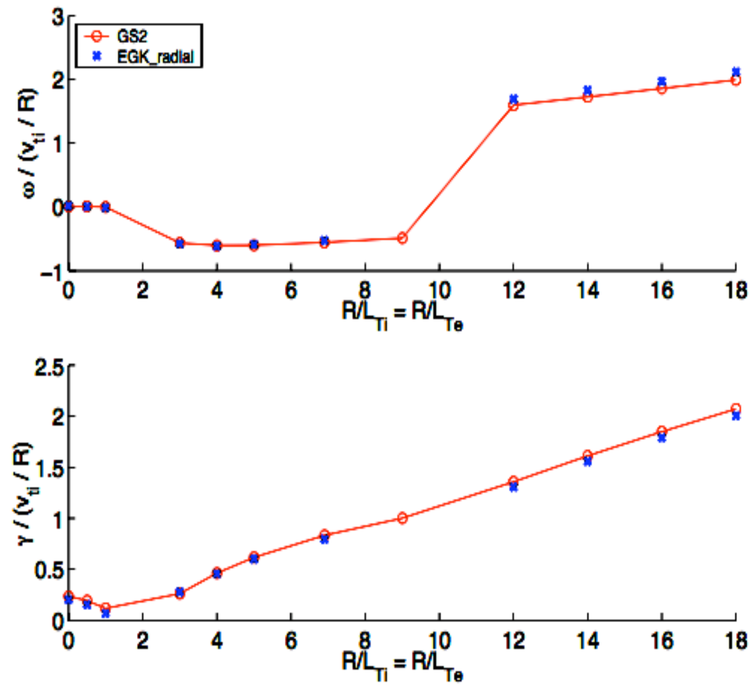




EGK Rapid-prototype code

Edge Simulation Laboratory

- Developing a full-f code, $v_{||}$-μ coordinates, simple geometry to
  - explore algorithms, physics of strong $v_{||}$ nonlinearity
  - serve as vehicle for EM solver development
- Current status:
  - Linearized code, radial + poloidal grids + n_{tor}
  - Adiabatic or kinetic electrons
  - ITG, TEM benchmarks vs. GS2
  - GAM tests



Math/CS Team activities

Edge Simulation Laboratory

- Technology for arbitrarily mapped multiblock grids (provides flexible options for dealing with sheared fields and edge topology)
- High-order finite-volume discretizations (in 5D)
- Assessment of time-advance strategies for differential-algebraic systems
- Upgrades to CHOMBO AMR framework to accommodate needs of ESL

We are headed for a code with the following:

Edge Simulation Laboratory

- Continuum solution to GK equations
- Full-f
- Extension of GK equations for improved applicability to edge problems
- Electromagnetic
- Full divertor geometry; full 2D equilibrium potential structure
- Runnable as 4-D ($\Psi,\theta,v_{||},\mu$; transport) or 5-D ($\Psi,\theta,\phi\ ,v_{||},\mu$; turbulence) code
- Conservative high-order finite-volume discretization
- Arbitrary mapped multiblock grids provide a range of options to handle magnetic shear
- Adaptivity to handle local structure in x or v
  - Built in AMR framework
  - Funding permitting: dynamic grid alignment (to follow large δB)
- Optional fluid equations in same framework

Other ESL-related presentations

- This session:
  - Xiong et al, “Verification of TEMPEST with neoclassical transport theory”
  - Belli et al, “Studies of Gyrokinetic Turbulence Models for Edge Plasmas
  - Xu et al, “5D Tempest simulations of kinetic edge turbulence”
  - Krasheninnikov et al, “Plasma equilibrium in the vicinity of X-point”
- Posters earlier this week:
  - JP1.00061, Rognlien et al, “Simulations of 4D edge transport and dynamics using the TEMPEST gyrokinetic code”
  - JP1.00062, Kerbel and Xiong, “Numerical Methods for Nonlinear Fokker-Planck Collision Operator in TEMPEST”
  - JP1.00063, Dorr et al, “Numerical Solution of the Gyrokinetic Poisson Equation in TEMPEST”
- PRESENTATIONS WILL BE POSTED AT PROJECT WEB SITE:

  http://esl.lbl.gov